Report No.: FHWA-KS-15-06 ▪ FINAL REPORT ▪ July 2015

The Effects of Supplementary Cementitious Materials on Alkali-Silica Reaction

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Kansas Department of Transportation
Bureau of Research

Kansas
Department of Transportation

1 Report No.
FHWA-KS-15-06

2 Government Accession No.

3 Recipient Catalog No.

4 Title and Subtitle
The Effects of Supplementary Cementitious Materials on Alkali-Silica Reaction

5 Report Date
July 2015

6 Performing Organization Code
SPR-73-1

7 Author(s)
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7 Performing Organization Report No.

9 Performing Organization Name and Address
Kansas Department of Transportation
Bureau of Research
2300 SW Van Buren
Topeka, Kansas 66611-1195

10 Work Unit No. (TRAIS)

11 Contract or Grant No.

12 Sponsoring Agency Name and Address
Kansas Department of Transportation
Bureau of Research
2300 SW Van Buren
Topeka, Kansas 66611-1195

13 Type of Report and Period Covered
Final Report

14 Sponsoring Agency Code

15 Supplementary Notes
For more information write to address in block 9.

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KDOT had traditionally banned Class C fly ash from concrete mixes due to their possible contribution to the ASR problem. Class C fly ash that could not meet the expansion requirements for Effectiveness in Controlling Alkali-Silica Reaction in Table 3 of ASTM C618 (2005), *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, was not allowed to be used in concrete mixes for KDOT projects.

Test sections that utilized selected mixes from this study were placed during the summer of 2008 in Wyandotte County, Kansas. The construction report for this project is available, and regularly scheduled surveys are being performed (Distlehorst, 2013).

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KDOT is currently evaluating threshold combinations of aggregates and SCMs to determine which combinations will require ASTM C1567 testing and which combinations can be approved without testing. This research is being conducted at the request of Kansas contractors due to the expense of the ASTM C1567 testing.

17 Key Words
Alkali-Silica Reaction, Cementitious Materials, Fly Ash, Aggregates

18 Distribution Statement
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19 Security Classification (of this report)	20 Security Classification (of this page)	21 No. of pages	22 Price
Unclassified	Unclassified	18	

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KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

July 2015

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Abstract

The Kansas Department of Transportation (KDOT) has controlled alkali-silica reaction (ASR) for more than 70 years through the use of selected aggregates. Sand and gravel sources had to be tested using Kansas Test Method KTMR-23 (1999), *Wetting and Drying Test of Sand and Sand-Gravel Aggregate for Concrete*. Those aggregate sources that did not pass the Wetting and Drying Test had to be used with a "sweetener." The sweetener had to make up a minimum of 30% (by weight) of the aggregate in the concrete. The most common sweeteners used have been limestone, calcite cemented sandstone, and a coarse gravel that passed the Wetting and Drying Test. Granite from Arkansas has recently been added as a sweetener in the Kansas City market.

KDOT had traditionally banned Class C fly ash from concrete mixes due to their possible contribution to the ASR problem. Class C fly ash that could not meet the expansion requirements for Effectiveness in Controlling Alkali-Silica Reaction in Table 3 of ASTM C618 (2005), *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, was not allowed to be used in concrete mixes for KDOT projects.

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In 2007, KDOT specifications were changed to allow supplementary cementitious materials (SCMs) in portland cement concrete. KDOT began accepting ASTM C1567 (2004), *Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)*, test results for concrete mixes containing SCMs. In 2009, the requirements of Table 3 of ASTM C618 were changed from 100% of the control mix to 120% of the control mix for Class C fly ash used in all concrete.

KDOT is currently evaluating threshold combinations of aggregates and SCMs to determine which combinations will require ASTM C1567 testing and which combinations can be approved without testing. This research is being conducted at the request of Kansas contractors due to the expense of the ASTM C1567 testing.

Acknowledgements

The Kansas Department of Transportation wishes to acknowledge the Central Plains Materials (formerly Lafarge North America) Kansas City Performance Center at Sugar Creek, Missouri, for their guidance and assistance in this research.

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Introduction

The Kansas Department of Transportation (KDOT) has controlled alkali-silica reaction (ASR) for more than 70 years through the use of selected aggregates. Sand and gravel sources had to be tested using Kansas Test Method KTMR-23 (1999), *Wetting and Drying Test of Sand and Sand-Gravel Aggregate for Concrete*. Those aggregate sources that did not pass the Wetting and Drying Test had to be used with a "sweetener." The sweetener had to make up a minimum of 30% (by weight) of the aggregate in the concrete. The most common sweeteners used have been limestone, calcite cemented sandstone, and a coarse gravel that passed the Wetting and Drying Test. Granite from Arkansas has recently been added as a sweetener in the Kansas City market.

KDOT had traditionally banned Class C fly ash from concrete mixes due to their possible contribution to the ASR problem. Class C fly ash that could not meet the expansion requirements for Effectiveness in Controlling Alkali-Silica Reaction in Table 3 of ASTM C618 (2005), *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, was not allowed to be used in concrete mixes for KDOT projects. However, in 1999, KDOT began allowing the use of Class C fly ash in concrete pipe. The requirements of Table 3 were increased from 100% of the control mix to 400% of the control mix for fly ash used in concrete pipe. Mix designs were tested according to Kansas Test Method KTMR-29 (2006), *Wetting and Drying Test of Steam Cured Reinforced Concrete Pipe with Fly Ash*, which is a modified version of KTMR-23 (1999). Fly ash may be substituted for Types II or I/II portland cement in concrete pipe at rates up to 25 percent. At the time of this study, all the fly ash mixes that had been approved for concrete pipe contained a minimum of 30% limestone sweetener.

KDOT has conducted numerous studies on the effects of Class C fly ash on ASR. All but one of those studies used total mixed aggregates (TMA; 100% siliceous sand and gravel). These studies compared the effects of fly ash on concrete produced with TMAs that both met and did not meet the wetting and drying requirements. Only one previous research project used limestone as an aggregate in the concrete mixtures. A study was conducted by former University of Kansas professors Mohamed Nagib Abou-Zeid and Stephen A. Cross, and retired KDOT Engineer John B. Wojakowski. The conclusions of that study indicate that the use of up to 15% fly ash will not adversely affect the ASR resistance or freeze-thaw resistance of concrete mixtures that contain at least 50% limestone (Abou-Zeid, Wojakowski, & Cross, 1996).

Two other developments have been introduced since 1995. Kansas developed readily available sources of ground granulated blast furnace slag (GGBFS) and a “blended” Class F fly ash. Both materials have been proven to mitigate ASR in concrete mixes. ASTM introduced a test procedure ASTM C1567 (2004), *Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)*. KDOT began evaluating the use of Class C fly ash and GGBFS in ternary blended cements in light of these two developments.

Initial Study Results

The initial study began in 2006 and utilized four different sources of coarse aggregate: Kansas River gravel, limestone, granite, and quartzite. The granite is from Arkansas and the quartzite is from South Dakota. They are included due to the requirements of the Kansas City Metropolitan Materials Board, which does not allow the use of limestone in concrete mixes. Two sources of Class C fly ash were used: Lafarge Lacygne and Lafarge Iatan. One source of blended Class F fly ash was incorporated into the study. Ash Grove Durapoz F is a blend of Class F fly ash and gypsum. All the fine aggregate, except Mix #1, is from the Missouri River, which is an aggregate that greatly contributes to ASR in concrete mixes. Mix #1 used a fine aggregate from the Kansas River which is not as reactive as the Missouri River sands, but has never passed the Wetting and Drying Test. Mixes #1, #2, and #13 used Monarch Type I/II cement from Humboldt, Kansas. All the other mixes used Lafarge Type I/II cement from Sugar Creek, Missouri. Mixes #1 and #2 were the control mixes consisting of TMA and no supplementary cementitious materials (SCMs). A summary of the mix designs is included in Table 1.

Table 1: Summary of Mix Designs

Mix Design	Coarse Source	% Coarse	Pea Gravel	% Pea Gravel	Fine Source	% Fine	SCM-1	% SCM-1	SCM-2	% SCM-2
1	KS River CA-5	MA-1	Holliday #7	MA-1	Control Mixes Graded to Middle 1/3 of MA-1. No SCMs					
2	KS River CA-5	MA-1	Holliday #11	MA-1						
3	Limestone	30%	Holliday #11	30%	Holliday #11	40%			Lacygne Type C	10%
4	Granite	30%	Holliday #11	30%	Holliday #11	40%			Iatan Type C	10%
5	Quartzite	30%	Holliday #11	30%	Holliday #11	40%	Slag	30%	None	
6	KS River CA-5	30%	Holliday #11	30%	Holliday #11	40%	Slag	30%	Lacygne Type C	10%
7	KS River CA-5	30%	Holliday #11	30%	Holliday #11	40%	Slag	30%	Iatan Type C	10%
8	Limestone	30%	Holliday #11	30%	Holliday #11	40%	Slag	30%	Iatan Type C	10%
9	Granite	30%	Holliday #11	30%	Holliday #11	40%	Slag	30%	Lacygne Type C	10%
10	Limestone	30%	Holliday #11	30%	Holliday #11	40%	Slag	25%	Iatan Type C	15%
11	Quartzite	55%	None		Holliday #11	45%	Slag	25%	None	
12	Granite	55%	None		Holliday #11	45%	Slag	25%	None	
13	Quartzite	55%	None		Holliday #11	45%			Type F Ash	25%
14	Granite	30%	Holliday #11	30%	Holliday #11	40%	None		None	

Note: Holliday #11 is MO River; Holliday #7 is KS River CA-5

The KTMR-23 (1999) Wetting and Drying Test takes one year to complete. Mix designs can be evaluated using ASTM C1567 (2004) within 16 days. All 14 mixes were evaluated by KDOT using KTMR-23. This procedure requires a 0.51 water-cementitious ratio. Aggregate is added to the mixture to bring the mix to a slump between 2 and 3 inches. The original Samples #1 and #2 were unable to obtain a slump of less than 3 inches due to a lack of appropriate aggregate. Therefore, the original Samples #1 and #2 were not included in this study. Replacement Samples #1 and #2 were produced in August 2006 to meet the requirements of KTMR-23. The original samples were retained for information only. All 14 of the KTMR-23 mixes were completed in August 2006. Additional selected mixes were evaluated by Lafarge using ASTM C1567.

The test results are listed in Table 2 of this report. All mixes met the 60-day Center Point Flexural Strength and 180-day expansion requirements of KDOT's Specifications for Mixed

Aggregates (KDOT, 2007). All KTMR-23 testing was completed by September 2007. Test sections were placed during the summer of 2008 in Wyandotte County, Kansas, utilizing select ternary mixes from this study. The construction report for this project is available, and regularly scheduled surveys are being performed (Distlehorst, 2013).

Table 2: Test Results

WET/DRY BEAMS									
Mix #	**% Slag**	**Fly Ash % - Source**	**Coarse % - Source**	**Fines % - Source**	**60 Day Strength**	**365 Day Strength**	**180 Day Length Change**	**365 Day Length Change**	**ASTM C1567**
1	0	0	KS - River	KS - River	564	**336**	0.036	**0.075**	
2	0	0	KS - River	MO - River	649	**528**	0.036	0.065	
3	0	10-Lacygne	30-Limestone	70-MO-River	748	776	0.008	0.023	**0.226**
4	0	10-Iatan	30-Granite	70-MO-River	754	**527**	0.019	**0.071**	**0.234**
5	30	0	30-Quartzite	70-MO-River	712	**335**	0.044	**0.162**	0.097
6	30	10-Lacygne	30-KS-River	70-MO-River	789	676	0.021	0.031	
7	30	10-Iatan	30-KS-River	70-MO-River	786	818	0.020	0.025	
8	30	10-Iatan	30-Limestone	70-MO-River	791	864	0.011	0.020	0.044
9	30	10-Lacygne	30-Granite	70-MO-River	819	894	0.022	0.026	0.037
10	25	15-Iatan	30-Limestone	70-MO-River	711	851	0.011	0.020	0.040
11	25	0	55-Quartzite	45-MO-River	835	**374**	0.048	**0.170**	**0.145**
12	25	0	55-Granite	45-MO-River	814	832	0.025	0.029	0.065
13	0	25% Class F	55-Quartzite	45-MO-River	823	920	0.012	0.014	
14	0	0	30-Granite	70-MO-River	675	744	0.026	0.037	**0.277**
8-1402	0	Control	Ark Rvr Fo Co	Ark Rvr Ke Co	705	817	0.009	0.014	
8-1403	0	15-Iatan	Ark Rvr Fo Co	Ark Rvr Ke Co	632	662	0.012	0.025	
9-1119	0	15-Iatan	TMA MW Conc Mat Riley Co		816	1208	0.013	0.069	
9-1236	0	25-Iatan	TMA MW Conc Mat Riley Co		840	564	0.008	0.059	
				SPEC	550 min	550 min	<0.050	<0.070	

non reactive	< 0.100
reactive	> 0.200

Discussion of Results

Mixes #1 and #2 demonstrate that the Kansas River and Missouri River sands from the Kansas City area are reactive to ASR and should not be used in KDOT concrete without a sweetener. Both mixes failed KDOT's KTMR-23 (1999) Wetting and Drying Test.

Mixes #3 and #4 demonstrate that neither 30% limestone nor 30% granite as a sweetener to Missouri River sand are enough to mitigate the ASR in the mixes with 10% fly ash and 0% slag. The limestone mix failed ASTM C1567 (2004), and the granite mix failed both the KTMR-23 Wetting and Drying Test and ASTM C1567. The use of 30% sweetener may mitigate ASR in fly ash mixes with less reactive sands, and this should be further investigated.

Mix #5 demonstrates that 30% slag may not be enough to mitigate ASR when quartzite and Missouri River sand are used as the aggregates in a concrete mix. Mix #5 failed the Wetting and Drying Test, but did pass ASTM C1567.

Mix #11 demonstrates that 25% slag is not enough to mitigate ASR when quartzite and Missouri River sand are used as the aggregates in a concrete mix. Mix #11 failed both the Wetting and Drying Test and ASTM C1567. The use of 30% to 35% slag should be investigated when quartzite and Missouri River sand are used as the aggregates in a concrete mix.

Mixes #6 and #7 indicate that 30% slag may mitigate the ASR when 10% fly ash is used in TMAs from the Kansas and Missouri Rivers. Both mixes passed the Wetting and Drying Test.

Mixes #8, #9, and #10 demonstrate that 25% to 30% slag is enough to mitigate ASR when 30% limestone or 30% granite is used as the sweetener in mixes that contain 10% fly ash. All three mixes passed both the Wetting and Drying Test and ASTM C1567. These three mixes show results better than 90% of the TMAs on the Wetting & Drying List (KDOT, n.d.).

Mix #12 demonstrates that 25% slag is enough to mitigate ASR in mixes consisting of 55% granite and 45% Missouri River sand. Mix #12 passed both the Wetting and Drying Test and ASTM C1567.

Mix #13 demonstrates that 25% Durapoz F is enough to mitigate ASR when 55% quartzite and 45% Missouri River sand are used in a concrete mix. Mix #13 passed the Wetting and Drying Test.

Mix #14 demonstrates the problem with testing mixes with 100% cement and no SCMs under ASTM C1567. Mix #14 passed the Wetting and Drying Test, but failed ASTM C1567. Most mixes without SCMs have not passed ASTM C1567, which may demonstrate a drawback in using this test procedure for 100% cement mixes.

Subsequent studies in 2008 and 2009 further investigated the use of Class C fly ash with TMAs that meet KDOT's Wetting and Drying Test requirements (KTMR-23, 1999). These results are also available in Table 2 and show that 15-25% fly ash can pass the Wetting and Drying Test with TMA on the Wetting and Drying List (KDOT, n.d.).

Test sections that utilized selected mixes from this study were placed during the summer of 2008 in Wyandotte County, Kansas. The construction report for this project is available, and regularly scheduled surveys are being performed (Distlehorst, 2013).

In 2007, KDOT specifications were changed to allow SCMs in portland cement concrete. KDOT began accepting ASTM C1567 (2004) test results for concrete mixes containing SCMs. In 2009, the requirements of Table 3 of ASTM C618 (2005) were changed from 100% of the control mix to 120% of the control mix for Class C fly ash used in all concrete.

KDOT is currently evaluating threshold combinations of aggregates and SCMs to determine which combinations will continue to require ASTM C1567 testing and which combinations can be approved without testing. This research is being conducted at the request of Kansas contractors due to the expense of the ASTM C1567 testing.

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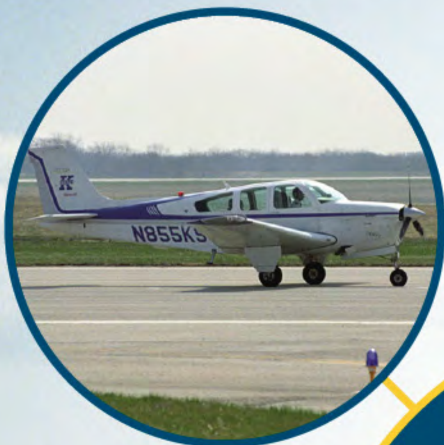

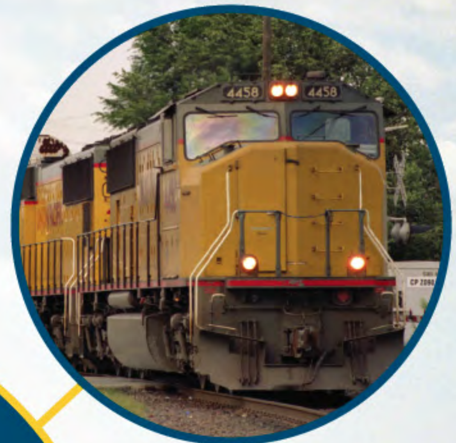

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